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Computerized Neuropsychological Assessment in 6–9 Years-old Children

Aleksey Korneev, Tatiana Akhutina, Aleksey Gusev, Alexander Kremlev, and Ekaterina Matveeva

Lomonosov Moscow State University, Moscow, Russia

Abstract

The article presents a new computer-based test battery of neuropsychological assessment in 6–9-year-old children. The battery consists of seven tests for assessing executive functions, functions of activation regulation, functions of visual-spatial information and auditory information processing. The following tests are described in the article: the Dots task, two-colored Schulte–Gorbov tables, Corsi block span test and Understanding of Similar Sounding Words test. The battery is developed in the software platform 'MSU-Practice' (http://psychosoft.ru). The system allows researchers to conduct the tests, collect data and analyze them. In addition, it includes cloud service to support the collaboration of different research groups. A total of 21 preschoolers, 52 first-graders and 114 second-graders took part in a pilot study. All three groups of children took the four computer tests and went through a neuropsychological assessment adapted for children between the ages of 5 and 9. The correlation analysis showed consistency between the results of the computer tests and the results of the neuropsychological assessments. This allowed us to conclude that the new computer methodology is sufficiently sensible and valid to assess different components of higher mental functions in children.

Keywords: neuropsychology, higher mental functions, primary school children, cognitive functions, computer-based tests

Corresponding Author:
Tatiana Akhutina
akhutina@mail.ru

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1. Introduction

The assessment of cognitive functioning in 6- to 9-year-old children is one of the developing directions in psychological science. Investigating cognitive functioning at this age is important for a theoretical understanding of cognitive development, and it is also important for the purpose of developing reliable methods for assessing the individual characteristics of children to identify learning difficulties and other developmental disabilities.

Various methods of objective assessment of cognitive functioning in children are used: observation, experiments, testing and methods of behavioral assessment. In the present study we describe a computerized method of neuropsychological assessment, developed by us in the tradition of Russian neuropsychology. This assessment is focused on evaluating the following cognitive functions in 5- to 9-year-old children: executive functions; functions of visual, visual-spatial and auditory information processing; and functions of activation regulation. Underdevelopment of these functions is a main cause of learning difficulties.

A variety of methods of assessing the cognitive and behavioral functioning in children and adults have been developed in the neuropsychological approach based on Vygotsky and Luria's ideas of systemic and dynamic organization and localization of higher mental functions (HMF; [1–6]). This approach is mainly based on qualitative assessment methods, with the results evaluated by an expert-neuropsychologist. This allows researchers to study in detail both the weaknesses and strengths of the HMF. However, the approach has a number of shortcomings. As some leading Russian and foreign neuropsychologists point out, the results of the diagnostics — expert estimates — are highly dependent on subjective factors: clinical experience, qualification, the theoretical approach of the expert and his/her individual style of conducting neuropsychological assessment (for a review, see [7–9]). Consequently, the results of the assessments obtained by different neuropsychologists are often incompatible; they do not have sufficient reliability. Furthermore, they are insufficiently detailed quantitatively, which makes it difficult to assess the dynamics of the children's HMF.

Thus, it seems important to develop a set of more standardized and objective methods that will unify procedures for both neuropsychological assessment and evaluation of its results without losing the idea of a systematic qualitative analysis, which is a distinctive feature of the Russian neuropsychological approach. In our opinion, such a battery should include tests which evaluate different components of HMF, based on all three functional blocks of the brain as described by A.R. Luria. This is the reason why we attempt to include the assessment of executive functions, related to block III of the brain, functions of visual and auditory information processing (block II) and functions of activation regulation (block I).

Modern versions of such techniques are computerized tests. There is a lack of computerized methods of cognitive function assessment in children in contemporary Russian neuropsychology. Computerized methods allow conducting research in a standard format and obtaining accurate and objective data. This will partly solve the problem of the experts' subjective differences. The automatic acquisition of assessment results and a standardized system of conducting the assessment may allow researchers to create a bank of reliable data for further scientific analysis.

We would like to emphasize that such computerized diagnostics are not meant to replace classical neuropsychological diagnostics. However, they can be used to conduct some large-scale studies and to identify children at risk, in order to further conduct detailed assessments and rehabilitation with these children. In this context, it is important to note that currently in Russian psychology there are no standardized computerized methods of neuropsychological assessment.

The creation of a computerized battery of tests of neuropsychological examination taking into account the experience of Russian neuropsychology is also important because at the present time such computerization of diagnostics is an actively developing direction in psychology. Modern technologies allow us to create and share such methods and systems, which is why today many traditional paper and pencil-based tests have become computerized. Bauer and colleagues [10] emphasize the strengths of a computerized assessment, such as speed, ease of use, accuracy of data registration, reduced costs and the ability to collect normative data. In general, during the most recent decades, computerized methods are widely used in psychology for research, diagnostics and rehabilitation of developmental disabilities of HMF (see [11] for a review). It is important to note that computerized tests are effectively used in the primary evaluation of large samples of children in order to identify those with difficulties and then to conduct a detailed examination of them using the more traditional qualitative methods [12].

Researchers who work with computerized methods in neuropsychology [10, 14] emphasize that, despite the ease of technical use of these methods, it is necessary to carefully monitor their quality, since the simple mechanical transfer of traditional paper-based tests into a computer form does not always preserve the quality of the technique. The creation of computerized tests should be accompanied by verification of their validity and the stability of the obtained results. Normative data, different from those collected for 'traditional' tests, should be obtained. It is also important to consider the age characteristics of children, including their fatigue and declining motivation.

All of these points should be taken into account when creating a system of computerized assessment of cognitive functioning. In this article, we present a set of procedures which is included in our assessment battery. We shall describe the results we collected, comparing them to those of classic qualitative neuropsychological assessment.

2. Methodology

The complete set of procedures included in the battery we are developing is as follows:

To assess the executive functions and functions of activation regulation we use the Dots task, the Schulte Tables task, the 1-Back Test (for children), and two versions of the Cancellation Test A-B-AB (non-verbal stimuli for preschool children and verbal stimuli for primary school children).

To assess the functions of visual-spatial information processing we use the Corsi block span test, Raven's Colored Progressive Matrices and the Test of Understanding of the Reversible Grammatical Constructions.

To assess the functions of auditory information processing, we use the Test of Understanding of Similar Sounding Words.

In this article, we shall describe some of these tasks and the results of their use.

The Dots task is used to evaluate the executive functions and functions of activation regulation. Traditionally, the task is referred to as the 'Dots task' [15]. It includes three subtests, and each subtest includes 20 stimuli. In response to a stimulus, the participant has to press particular keyboard keys, according to the instruction. The first subtest ('congruent') estimates a person's general ability to follow instructions and the speed of a simple motor response. A stimulus (a heart) appears on the screen in quasi-random order, either to the left or to the right of a fixation cross (see Figure 1FA). The participant is instructed to press (as soon as possible) the key on the left if the stimulus appeared on the left, or to press the key on the right if the stimulus appeared on the right. The second subtest ('incongruent') estimates the ability to suppress 'natural' reactions, irrelevant to the task. When the stimulus (a flower) appears on the screen, the participant has to press (as soon as possible) the key on the left or on the right, opposite to the side where the stimulus appeared (see Figure 1B). The third subtest evaluates the child's ability to switch between two parallel programs. In this subtest, two types of stimuli appear in mixed order (hearts or flowers, see Figure 1C). The participant is asked to press the key on the same side as where the heart appeared and to press the key on the opposite side of where the flower appeared. This task is more difficult and 'energy-demanding' and thus is more sensitive to the state of the functions of brain blocks III and I.

The output variables in this task are: the mean reaction time and the number of the errors made in first, second and third subtests.

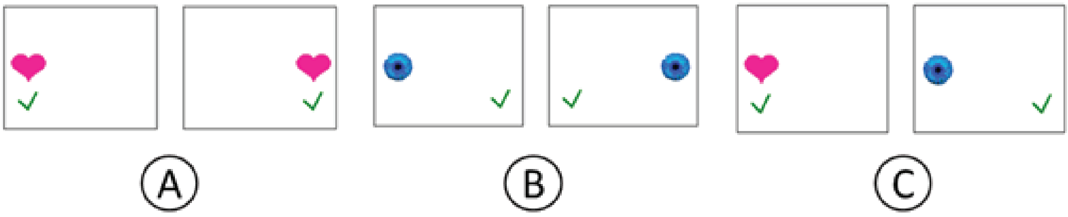

Figure 1: Illustration of the 'Dots' test procedure: A – first subtest (congruent); B – second subtest (incongruent); C – third subtest (mixed).

The two-colored Schulte–Gorbov tables test, modified for preschool children and primary school age children, evaluates the executive functions and states of the activation processes.

The test includes five trials. In each trial a table is presented on the touch screen, consisting of 20 cells (5 × 4), in which two rows of numbers from 1 to 10 are arranged in a quasi-random order, one row consisting of black numbers, the second consisting of red numbers (see Figure 2).

5	7	4	9	6
2	9	3	8	1
1	10	3	8	2
5	7	4	10	6

Figure 2: A two-colored Schulte–Gorbov table.

The participant is instructed to search and indicate numbers in different orders. In the first trial, he or she is asked to show the black numbers in ascending order (from 1 to 10); in the second, red numbers in ascending order; in the third, black numbers in descending order (from 10 to 1); in the fourth trial, to indicate two parallel rows, with red and black numbers in ascending order: 1 black, 1 red, 2 black, 2 red, etc. Finally, in the fifth trial, the participant is instructed to show the red numbers in descending order. The test should be performed as fast as possible, but the time is not limited. This task allows researchers to evaluate the ability of children to follow a simple program (first two trials), the more complex reverse program (third and fifth trials) and the most complex 'parallel' program (fourth trial), switching the attention from one program to another and suppressing irrelevant reactions. In this way, the functions of block III of the brain are evaluated. The long duration of the technique, which requires stable maintenance of attention, makes it possible to study the state of the activation processes (block I of the brain). The sequence of tasks is constructed in such a way as to give an additional opportunity to assess the difficulties of entering the task (comparing trials 1 and 2) and fatigue (comparing trials 3 and 5).

The output variables are the speed and accuracy of the reactions in the five trials individually and in total. Moreover, the errors are registered in each trial: the quantity of color substitutions (e.g., indicating a red number instead of a black number), the quantity of double clicks on the already indicated number and the quantity of missing numbers.

The Corsi block tapping test evaluates visual-spatial span; it is sensitive to visual-spatial information processing and executive functions.

Nine blocks appear on the screen. The cubes flash sequentially, one after another (see Figure 3). Each block flashes for one second, with an interstimulus interval is 0.5 seconds. The participant is instructed to remember and to reproduce the sequence of the blocks. The first trial includes a sequence of two blocks. If the response is correct, the next trial with a longer sequence of blocks begins (one more cube is added). If the response is not correct, the next sequence has the same length. If there is a sequence of five false responses, the task terminates.

The following output variables are registered in the Corsi block-tapping test:

- maximum length of the correctly reproduced sequences;
- mean speed of the first response in each trial;
- mean speed of the subsequent responses within the trial;
- number of perseverations – rapid repetition of the response;
- number of duplications – slow repetition of the response;
- number of misses – pressing outside the blocks.

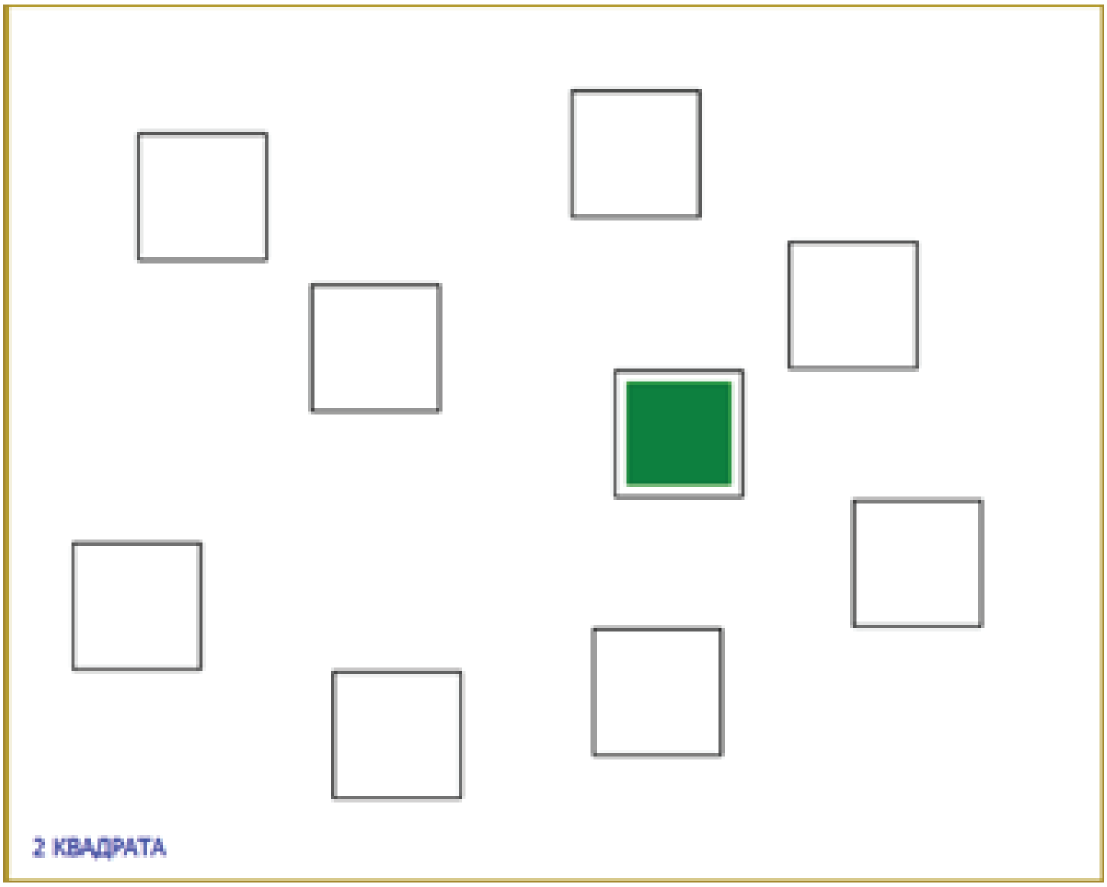

Figure 3: The screen in the Corsi block-tapping test.

The Understanding of Similar Sounding Words test evaluates the functions of auditory information processing. This test is adopted from the 'Method of language evaluation in aphasia' battery [16]. It is sensitive to both phonemic hearing and audio-verbal memory in children – thus, it is very sensitive to the processing of auditory information. In the beginning of the task, ten pictures of objects are presented. The names of these objects are similar sounding words or similarly pronounced words. They are *'tochka – dochka – bochka – pochka'* (dot, daughter, barrel, bud), '*trava – drova'* (grass, firewood), *'kossa – koza'* (braid, goat), '*miska – mishka'* (bowl, teddy bear); see Figure 4. Sequences of words are presented (there are eight sequences from two to five words in length), and the child is instructed to indicate the pictures in the same order as in the sequence of words.

The following variables are used to indicate the efficiency of task performance:

- quantity of the correctly reproduced words;
- maximum level of complexity of a correctly executed task;
- speed of the responses;

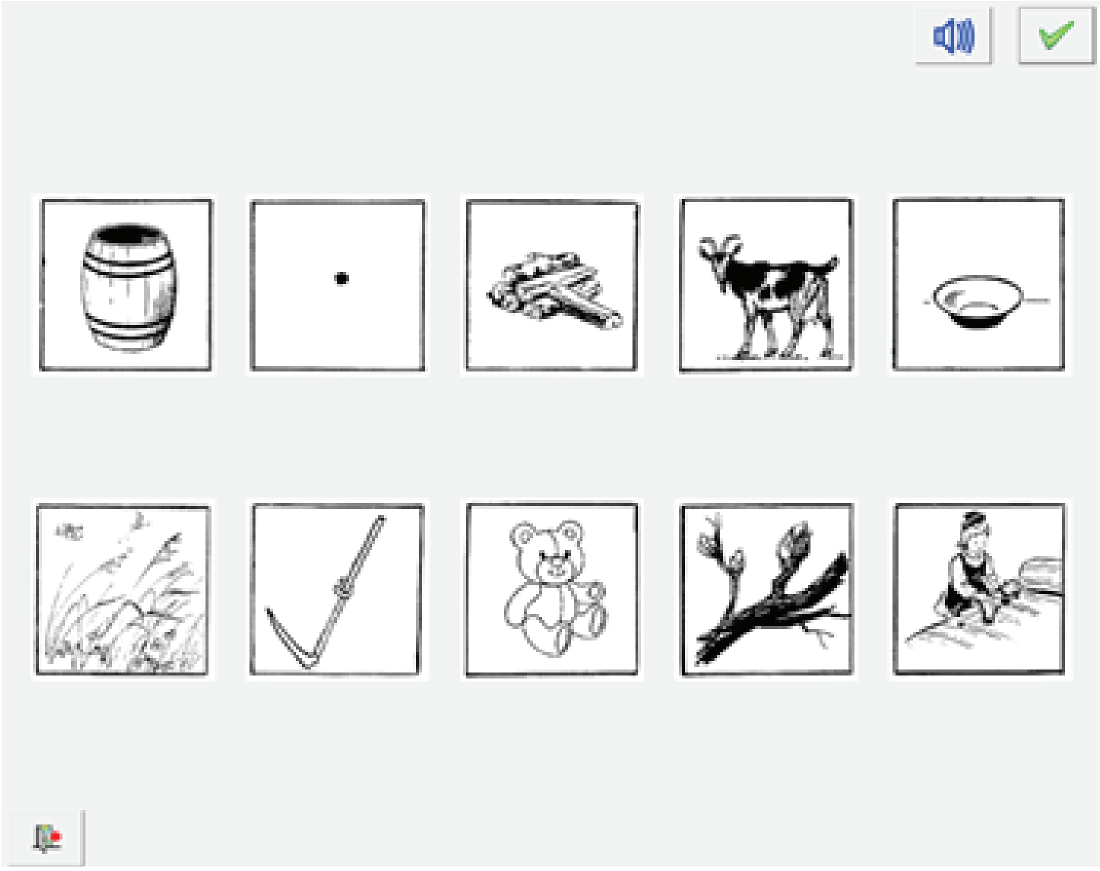

Figure 4: Stimuli used in the Understanding of Similar Sounding Words test.

- accuracy (correctness) of the responses;
- efficiency – a product of speed and accuracy.

Additionally, the errors typically traced during neuropsychological assessment are registered:

- similar substitution: substitution with a similar sounding word, for example, «*mishka*» instead of «*miska*» (teddy bear instead of bowl);
- doubling: in response to one stimulus, a correct answer + a substitution with a similar sounding word;
- far substitution: the substitution of the indicated word with a dissimilar one, for example, «*drova*» instead of «*dochka*» (firewood instead of daughter);
- adding an irrelevant word;
- missing the indicated word; and
- error in word order.

All tasks were conducted on a computer system base 'Practice-MSU' (developed by A.E. Kremlev and A.N. Gusev). The battery of tasks was implemented in the system. A brief description, link for download and short installation manual can be found at http://www.psy.msu.ru/about/lab/neuropsy/akhutina-2017.html. The 'Practice-MSU' system includes cloud service to support the collaboration of different research groups. That is, the data are collected and kept on servers; the users can then exchange their data, create cloud accounts, collect databases of testing norms and exchange messages with colleagues in 'Practice-MSU' and some other services which support group work. Nonetheless, the data are protected and accessible only to the user who created the database. The user may choose to exchange his/her data with some other users of the professional community and colleagues.

3. Results

In this article, we describe a pilot study which tests the validity of a set of computerized tasks and their sensitivity, compared to traditional neuropsychological tasks. Preschoolers ($N = 21$), first grade students ($N = 52$) and second grade students ($N = 114$) took part in the study. All children completed the Dots task, the Two-colored Schultz–Gorbov tables task, the Corsi block-tapping test, and the Understanding of Similar Sounding Words test. All children underwent neuropsychological assessment adapted for children 5–9 years of age [2], which allowed us to estimate the external validity of the computerized tasks we constructed. Based on the assessments, we calculated indexes of the following functions: executive functions, functions of serial organization of movements, functions of auditory and visual-spatial information processing and functions of activation regulation. These indexes are calculated using a penalty point system: the higher the index, the worse the neuropsychological estimation of the function.

Correlation analysis was conducted in order to evaluate the coherence between the results of neuropsychological assessments and computerized tasks. The correlation analysis revealed the following:

1. The productivity (number of correct answers) of the third subtest (the most difficult) of the Dots task correlates with the indexes of executive functions ($r = -0.214$, $p = 0.016$) and functions of serial organization of movements ($r = -0.184$, $p = 0.038$). The productivity of the second subtest has a tendency toward statistical significance with the indexes of executive functions ($r = -0.156$, $p = 0.08$) and a statistically significant correlation with the indexes of functions of serial

organization of movements (r = −0.18, p = 0.038). It should be also mentioned that the efficiency of the first subtest correlates with the indexes of functions of activity regulation (r = −0.196, p = 0.027).

2. The mean reaction time in the two-colored Schulte–Gorbov tables task correlates with the indexes of executive functions (r = 0.432, $p < 0.001$); the highest correlation is with the most difficult, fourth trial (r = 0.422, $p < 0.001$). The mean reaction time also correlates with functions of serial organization of movements (r = 0.414, $p < 0.001$) and functions of visual-spatial information processing (r = 0.399, $p < 0.001$). The quantity of errors in this task also show correlations with the indexes of executive functions (r = 0.224, p = 0.01), functions of serial organization of movements (r = 0.264, p = 0.002) and functions of visual-spatial information processing (r = 0.247, p = 0.004).

3. The main output variable in the the Corsi block-tapping test – the maximum length of the correctly reproduced sequence – correlates with the indexes of the functions of visual-spatial information processing (r = −0.228, p = 0.002), as well as with executive functions (r = −0.250, p = 0.001) and functions of serial organization of movements (r = −0.216, p = 0.002).

4. The productivity of performing the Understanding of Similar Sounding Words test correlates with the indexes of the functions of auditory information processing (r = −0.434, $p < 0.001$), as well as with the indexes of executive functions (r = −0.262, $p < 0.001$).

4. Conclusions

The results of the experiment of new computerized methods and the comparison of these results with those obtained with a classic neuropsychological assessment confirmed that the computerized tools are sufficiently sensitive and valid to assess different components of the HMF.

In future studies, we plan to include more tasks in our computerized assessment battery in order to evaluate cognitive processing of children in more detail. Moreover, we plan to develop a system-oriented analysis of the obtained data and to construct neuropsychological profiles of children, reflecting the interplay between their HMF.

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